CAN AUDITORY DISPLAY HELP US CATEGORIZE SEISMIC SIGNALS?

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ABSTRACT

Recordings of the Earth's surface oscillation (seismograms) can be sonified such that most of the signal's frequency spectrum falls in the audible range. Then, the pattern-recognition capabilities of the human auditory system can be applied to auditory analysis of seismic data. We sonify seismograms associated with a magnitude 5.6 earthquake. A group of volunteers listen to our sonified data set via headphones and software allowing them to reproduce each signal as many times as they want by clicking on the corresponding icon. Following the "free categorization" approach, listeners are asked to group icons corresponding to sounds perceived as "similar." The goal of this test is to determine whether the human auditory system can perceive relevant "clues" in sonified seismograms, and whether humans can group such stimuli accordingly. Our results suggest that this is indeed the case, and allow us to identify at least one categorization strategy followed by the majority of listeners, which suggests that auditory analysis of seismic data is feasible and possibly useful. Our findings encourage further work, where we plan to take advantage of recent progress in auditory scene synthesis algorithms and spatial audio technology.

1. INTRODUCTION

Starting in the early 1960s [1], it has often been suggested that sonification and auditory analysis could contribute to research in seismology. A small community of researchers has sonified seismic data for a number of (often educational or artistic) applications [2]; even though interest around seismic sonification seems now to be growing [3, 4], the capability of the human auditory system to recognize patterns in seismic sound has not been studied quantitatively. This work is a first attempt at evaluating whether and to what extent auditory analysis can provide useful insight into seismic data.

2. SEISMIC DATA SET

We sonify broadband, vertical-component recordings (Fig. 1) of the November 6, 2011 magnitude-5.6 Oklahoma earthquake[5], made at 17 stations at local (<500km) epicentral distances. This event has been selected for the large quantity and high quality of available data recorded locally at diverse azimuths and distances, for the reliability of hypocenter locations, and for the perceived quality of sonified signals.

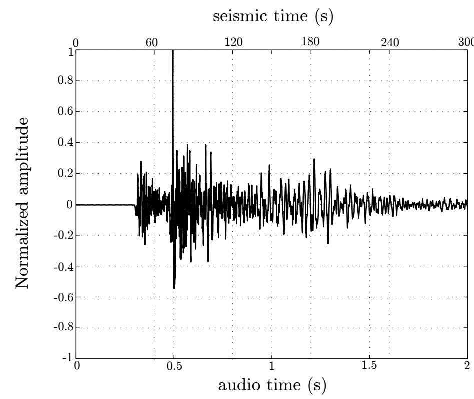

Figure 1: Seismogram associated with a magnitude 5.6 event, recorded at a relatively far station (the compressional- and shear-wave arrivals are well separated).

3. SONIFICATION OF SEISMIC SIGNALS

Seismograms were sonified by a simple change of sampling frequency, from 40 Hz to 6000 Hz; this corresponds to playing signals 150 times faster than their actual speed, translating them to the audible frequency range. Much of the signal that is usually analyzed by seismologists falls within the "attack" and in the first part of the "coda" (or "resonance"), which are presented here to the subjects: the audio signals have a 2s-duration, corresponding to seismic signals of duration 300s.

The dynamic range of seismic signals is greater than that of audio signals, so we normalize each sonified signal with respect to its maximal value. This way, even though signal attenuates quickly as spherical seismic waves propagate away from the source, sonified signals recorded at large distances from the epicenter can still be heard and analyzed.

All sounds are available online at `http://hestia.upmc.fr/∼boschil/sonification.html`.

4. EXPERIMENTAL PROTOCOL

24 subjects took part in the experiment. 10 subjects are geoscientists, 4 are sound technicians, and 10 are acousticians. An exter-

nal soundcard connected to a computer was used for playing the sounds. Headphones were plugged to the output of the soundcard. Subjects used the *TCL-LabX* software[6] to complete the proposed free categorization exercise. This graphic interface displays stimuli as square icons, that can be clicked to play back the sounds, and dragged around the screen to form groups.

Because we do not know a priori whether the physical parameters in our experiment (e.g., the magnitude of an earthquake) can be linked to measurable psychological parameters (e.g., perceived loudness), we apply the free categorization method [7, 8], which requires no prior knowledge of the subjects' response to "seismic" stimuli. Each subject is asked to group together stimuli which seem similar, and put in different groups those that seem different. No information about the nature of the data (other than that they were originated from seismograms) was provided. The subjects are allowed to group all stimuli into one group, and/or to form groups that contain a single stimulus ("singleton" groups). All stimuli must belong to a group, and no stimulus can belong to two different groups.

The goal of this test is not (yet) to test any specific hypothesis as to how the stimuli are grouped, but, rather, to determine whether the subjects are grouping stimuli in any coherent way at all.

5. RESULTS

Our first observation is that, instructed to form groups of stimuli, the subjects did manage to do so. Fig. 2a shows the distribution of the number of categories in individual partitions. No subject chose to form one single group containing all stimuli, or to form as many singleton groups as there were stimuli. While differences between stimuli within a group might be perceived, subjects have nevertheless recognized common properties, that allowed them to group the stimuli together. Fig. 2b shows the distribution of the number of stimuli in categories. 34 categories contain only 1 stimulus, but the large majority of the other categories contain 2 to 6 stimuli. We conclude that the subjects suceeded in producing a categorization of the sound stimuli.

We next analyzed all individual test results, to find that 11 subjects (i.e., about half our sample) sorted the stimuli according to fairly similar criteria. All 11 subjects in this subset placed two particular pairs of stations in one category each; about half of them group together another specific pair of stations; finally, 5 out of 11 formed a category that contained the same three stations. The main criteria that have been followed appear to be (i) the spacing between the two main peaks of each signal, corresponding to the compressional- and shear-wave arrivals, and (ii) the frequency content, which is probably related to crustal structure and composition between source and receivers. Future work will seek to understand how and to what extent people can learn and be trained to identify physical causes for differences in seismic signals.

6. ACKNOWLEDGMENT

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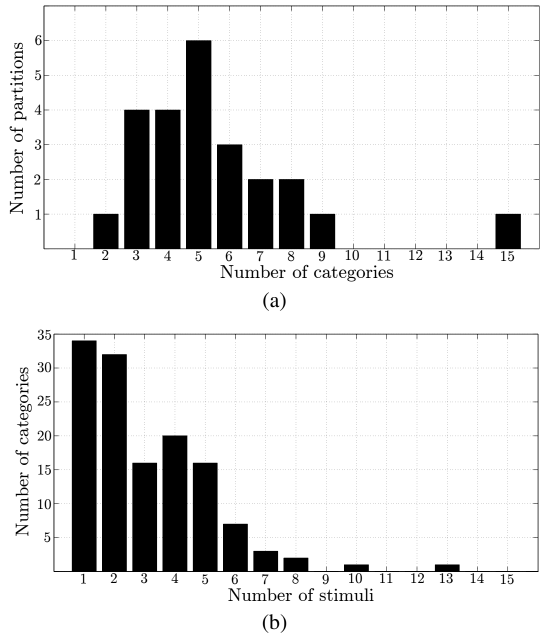

Figure 2: (a) Histogram plotting the distribution of the number of categories in partitions. (b) Histogram plotting the distribution of the number of stimuli in categories.

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